Near-real-time Satellite Cloud Products For Icing Detection And Aviation Weather Over The USA

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Acknowledgements

- John Murray, ASAP/AVSP NASA LaRC
- Tom Ratvasky and NASA Glenn Twin Otter Icing Team

OBJECTIVES

• Develop a satellite-based icing detection methodology that can be applied operationally with results provided in a timely manner as part of an integrated icing product for the aviation community

• Use satellite data to provide near-real time cloud-top & base altitudes for aviation weather applications

OUTLINE

- **DESCRIPTION OF METHODOLOGY AND CLOUD PRODUCTS**

  (Minnis)

- **RELATING AIRCRAFT ICING TO SATELLITE CLOUD PARAMETERS**

  (Smith)

- **DEMONSTRATION OF PROTOTYPE PRODUCT**

  (Minnis)

APPROACH

- **Use cloud properties currently being derived from satellite data at various time and space scales and relate them to aircraft icing**

-Developed & applied algorithms to various satellite (GOES, AVHRR, etc.) data for field programs for climate research

- Currently deriving global cloud and radiation parameters from EOS sensors for global change studies as part of the Clouds and Earth's Radiant Energy System (CERES) Experiment post processing

- Applying similar algorithms to 4-km GOES data to derive cloud and radiation parameters for DOE ARM program over SGP, for NASA CRYSTAL(FL), Icing (Midwest) running experimentally in R/T

PIXEL-LEVEL CLOUD PROPERTIES

EFFECTIVE RADIATING TEMP	**Tc**
EFFECTIVE HEIGHT, PRESSURE	**Zc, pc**
TOP PRESSURE, HEIGHT	p_t, z_t
THICKNESS	**h**
EMISSIVITY	ε
PHASE (water or ice; 1 or 2)	**P**
WATER DROPLET EFFECTIVE RADIUS	**re**
OPTICAL DEPTH	τ
LIQUID WATER PATH	**LWP**
ICE EFFECTIVE DIAMETER	**De**
ICE WATER PATH	**IWP**

Blue indicates utility for icing

ICING

ICING CONDITIONS ARE DETERMINED BY CLOUD

- liquid water content, *LWC* **positive w/ intensity**
- temperature, $T(z)$ **negative w/ intensity**
- droplet size distribution, $N(r)$ ***r* positive w/ intensity**

SATELLITE REMOTE SENSING CAN DETERMINE CLOUD

- optical depth, τ
- effective droplet size, *re*
- liquid water path, *LWP*
- cloud top temperature, *Tc*
- thickness, *h*

IN CERTAIN CIRCUMSTANCES

CLOUD PRODUCTS VS. ICING PARAMETERS

- $LWP = LWC * h$

- re = f[$N(r)$]

- Tc & h can yield depth of freezing layer

- z_t is top of icing layer

- ceiling = $z_t - h$

IN MANY CASES, SATELLITE REMOTE SENSING
SHOULD PROVIDE ICING INFORMATION

DATA

- GOES-8 IMAGER (4KM RESOLUTION)   75° W

Visible (0.63 µm; ch.1)
Solar Infrared (3.9 µm; ch.2)
IR Window (10.8 µm; ch.4)
Split Window (12.0 µm; ch.5) (G-12: 13.3 µm)

Visible Channel Calibrated Following Minnis et al. 2002

- Rapid Update Cycle (RUC) 20 km x 20 km hourly analyses

- surface air temperature => skin temperature
- temperature & moisture profiles => absorption correction, heights

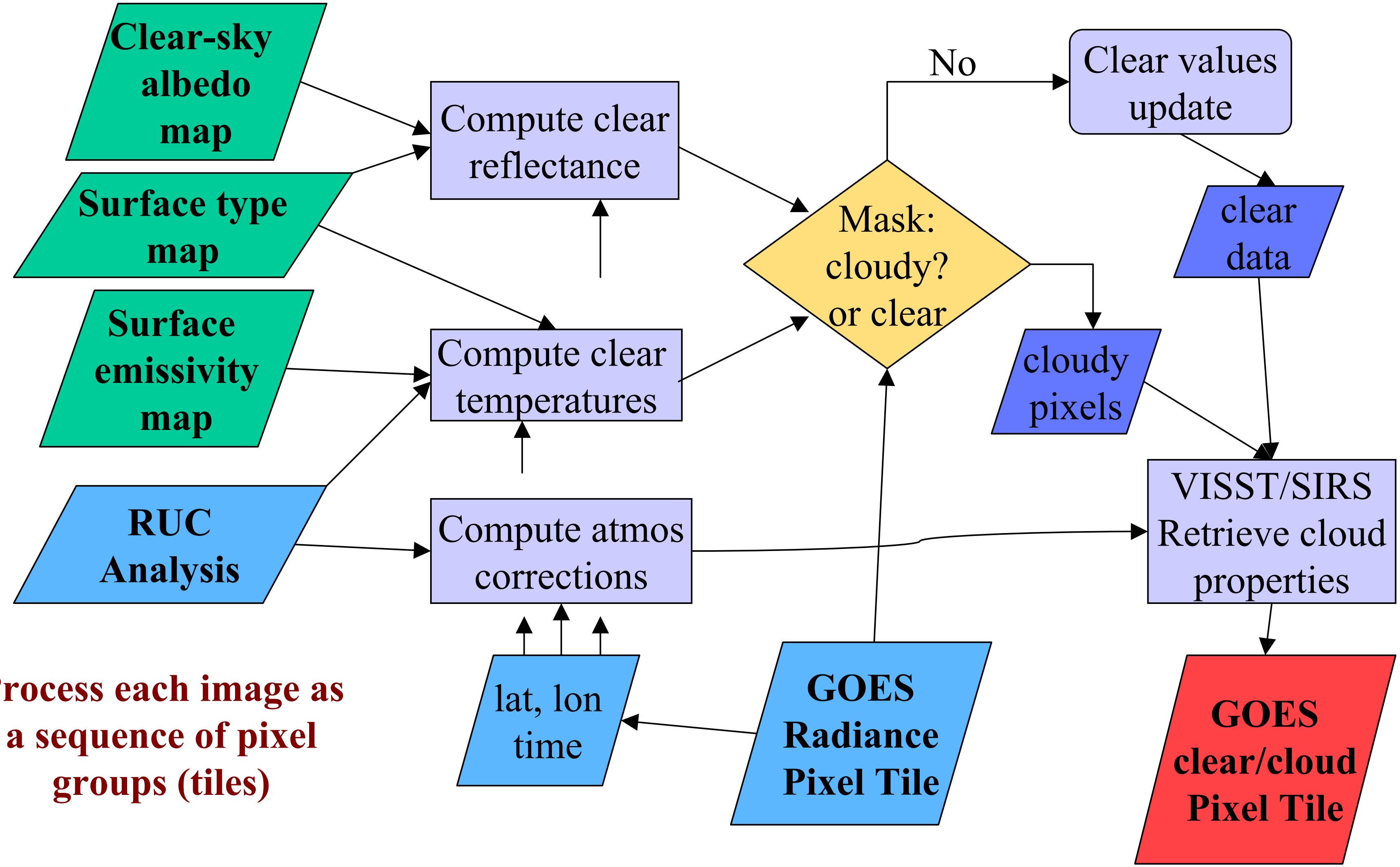
- CERES clear-sky albedo, surface emissivity (10', 1°)

clear-sky reflectance, brightness temperature => cloud detection/retrieval

- Theoretical cloud reflectance & emittance models

describes angular variation for range of re and τ => cloud detection/retrieval

METHODOLOGY FOR EACH IMAGE TIME



Process each image as a sequence of pixel groups (tiles)

CLOUD MASK

- To detect clouds, the radiances for cloud-free (clear) scene must be known

- Determine clear-sky albedos and surface emissivities after initial processing of data

    - start with CERES values and update

- Use RUC surface temperatures & profiles to estimate clear-sky brightness temperatures

- Must account for angular dependence: bidirectional reflectance models to estimate clear-sky reflectance for each pixel

- Estimate thresholds based on uncertainties in models & spatial/temporal variability of the clear radiances

CLEAR-SKY RADIANCE CHARACTERIZATION

• **Predict radiance a given satellite sensor would measure for each channel if no clouds are present**

• **Estimate uncertainty based on spatial & temporal variability & angular model errors**

• **Develop set of spectral thresholds for each channel**

- **Solar, uses reflectance, ρ**
- **IR, use temperature, T**

brightness temperature difference, BTD = $T_{\lambda 1} - T_{\lambda 2}$

typically, BTD(3.7-11) or BTD(11-12)

CLEAR-SKY REFLECTANCE, SOLAR

- **Estimate overhead-sun albedo,** $\alpha_o = \alpha(\mu_o = 1)$

  derived empirically with initial runs usingCERES VIRS data,
  then updated for each month using GOES

- **Estimate albedo at given local time,** $\alpha(\mu_o) = \alpha_o\, \delta_o(\mu_o)$

  directional reflectance model $\delta_o(\mu_o)$ *derived for each IGBP type using VIRS*

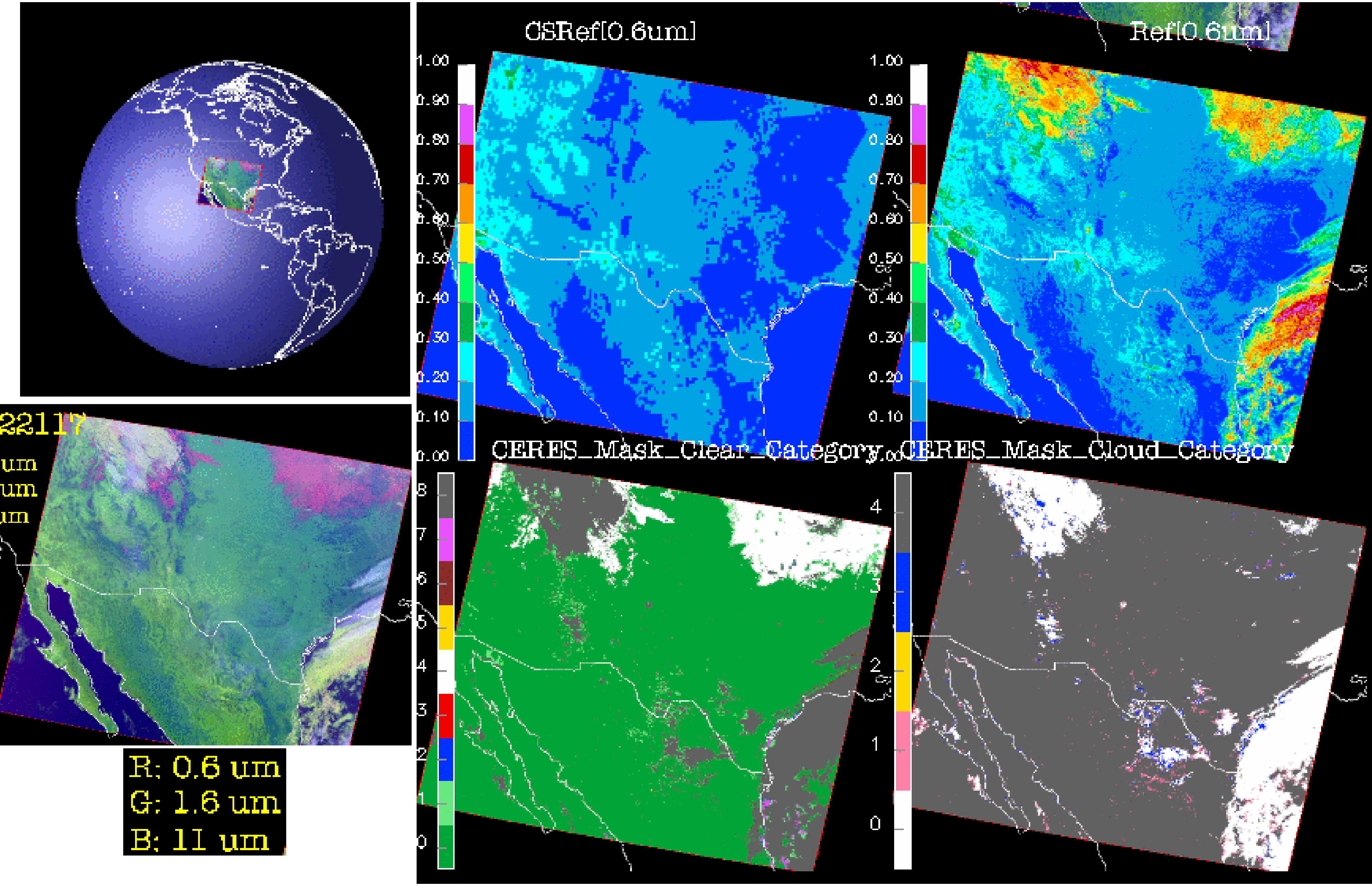
- **Estimate reflectance for given viewing angles,** $\rho(\mu_o, \mu, \phi) = \alpha(\mu_o)\, \chi(\mu_o, \mu, \phi)$

  bidirectional reflectance (BRDF) model χ *selected for each surface type*

  from Kriebel (1978), Minnis & Harrison (1984), Suttles et al. (1988)

- **Add uncertainty to set reflectance threshold,** $\rho_{\square}(\mu_o, \mu, \phi) = \rho + \Delta\rho(\mu_o, \mu, \phi)$

PREDICTED CLEAR-SKY & OBSERVED VIS REFLECTANCE & CLOUD MASK
1700 UTC,12/21/00



CLEAR-SKY TEMPERATURE, INFRARED

- **Estimate surface emissivity, $\varepsilon_s(x,y)$**

  derived empirically with using ISCCP AVHRR DX, VIRS, then Terra MODIS; water & snow theoretical models

- **Estimate radiance leaving the surface, $L_s = \varepsilon_s B(T_{skin}) + (1-\varepsilon_s)L_{ad}$**

  L_{ad} = downwelling atmo radiation, T_{skin} = skin temperature from model / obs

- **Estimate TOA brightness temperature, $B(T_{cs}) = (1-\varepsilon_a)L_s + \varepsilon_a L_{au}$**

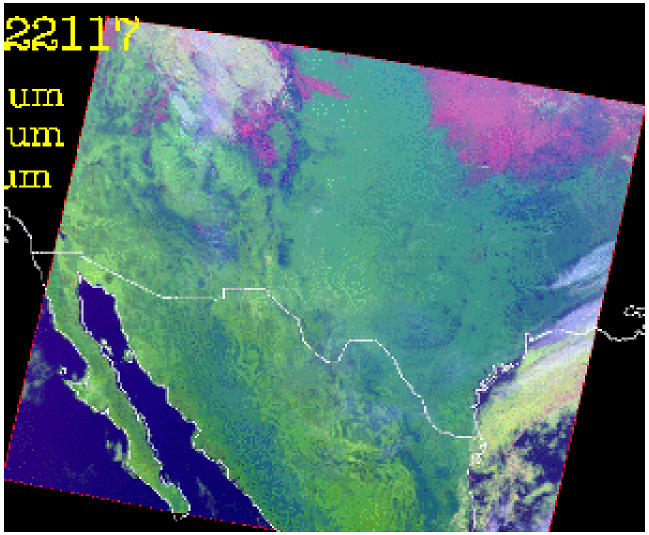
  L_{au} = upwelling atmo radiation, ε_a = effective emissivity of atmo

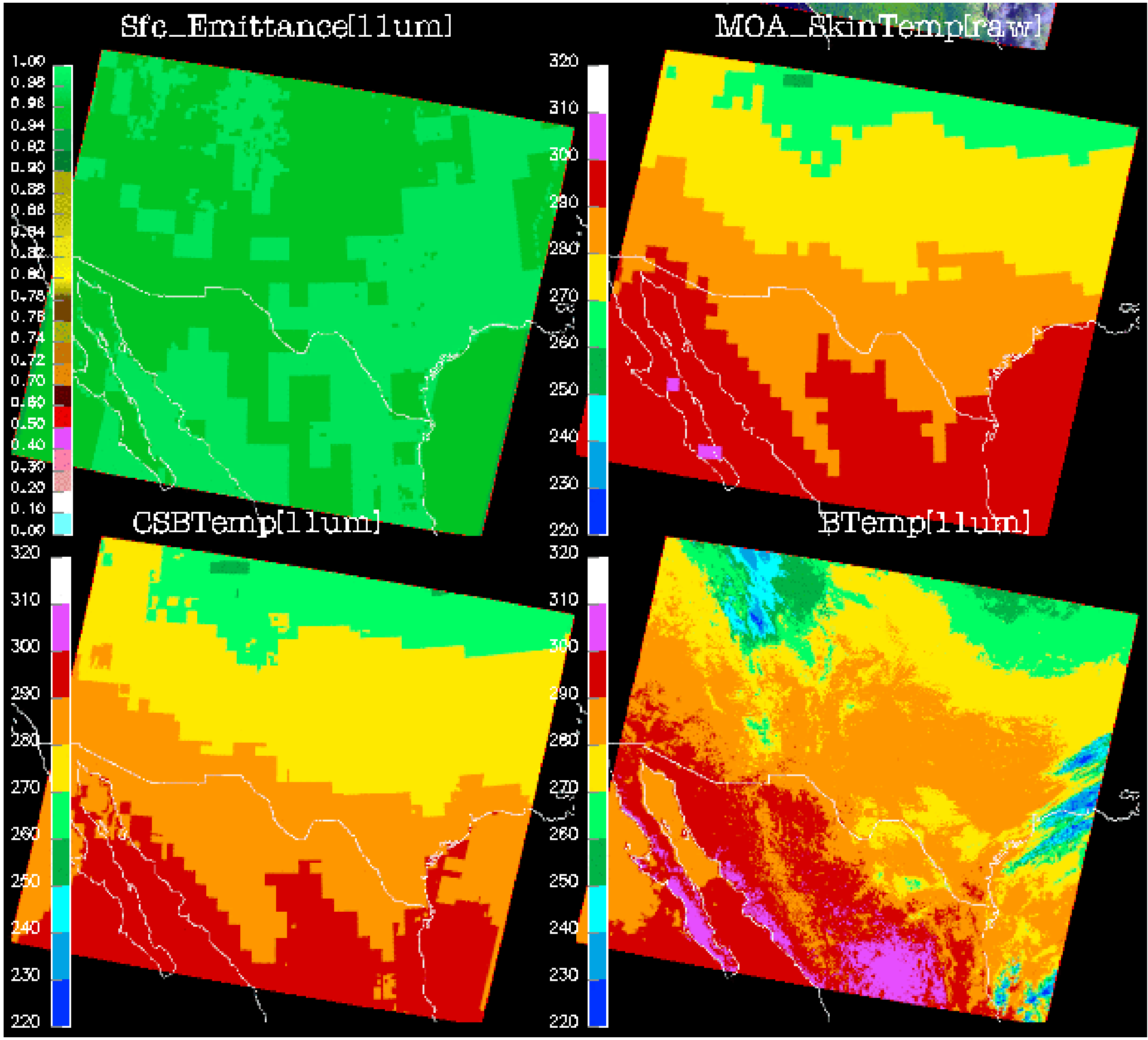
  layer absorption emission computed using T/RH profile, correlated k-dist

- **Add uncertainty to set T or BTD thresholds, $\square_{\square}(\mu) = T_{cs}(\mu) + \Delta\square(\mu)$**

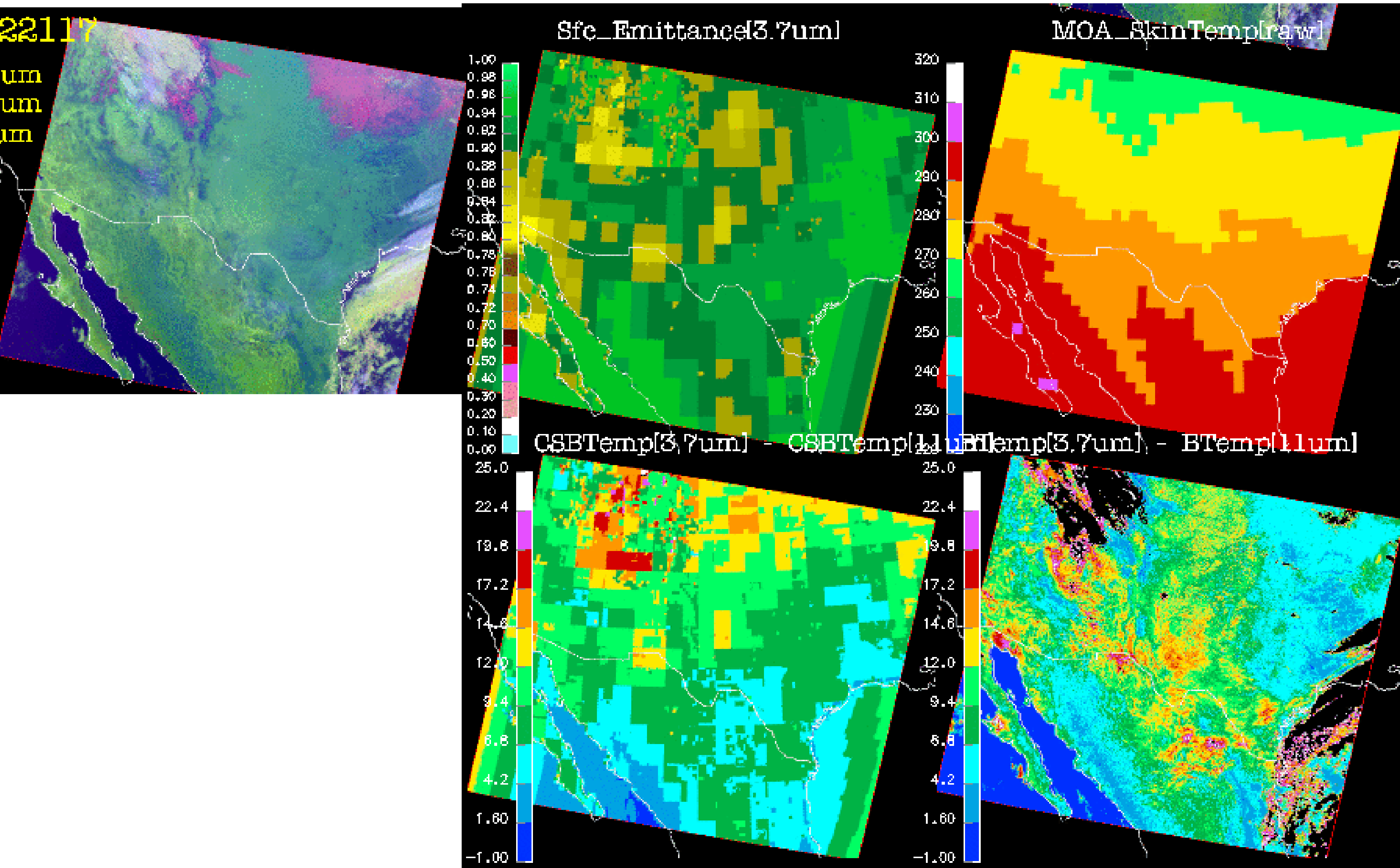
  - reflected solar component included in 3.7-4.0 µm estimate

PREDICTED CLEAR-SKY & OBSERVED IR TEMPERATURE
1700 UTC,12/21/00

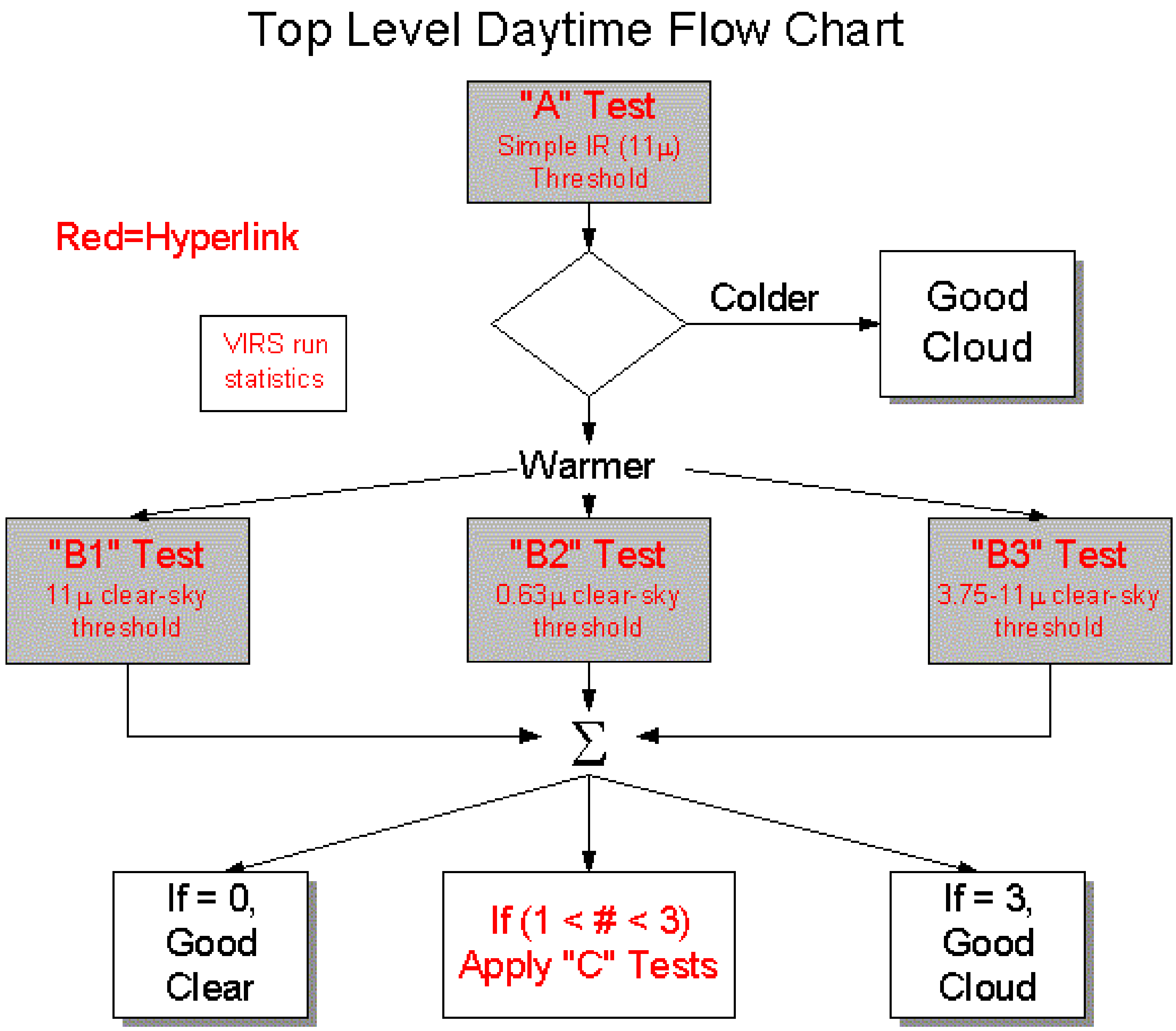


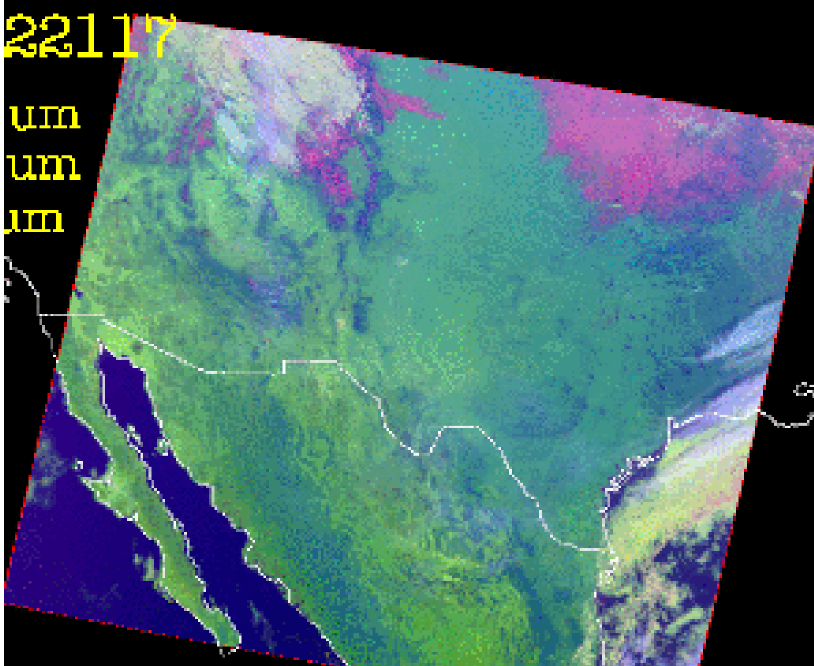


PREDICTED CLEAR-SKY & OBSERVED BTD (3.7 - 11)
1700 UTC,12/21/00

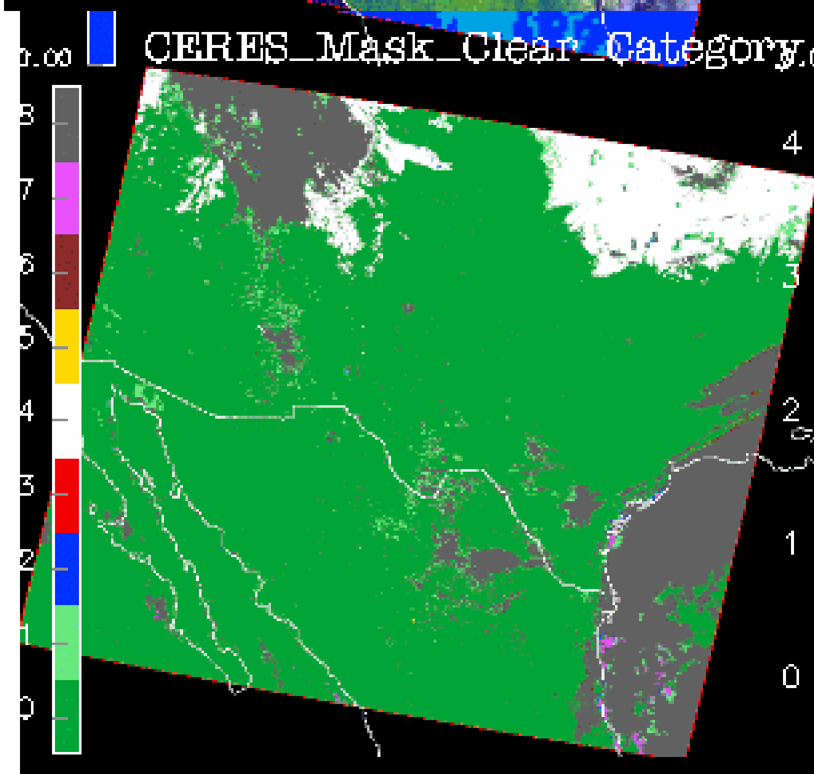


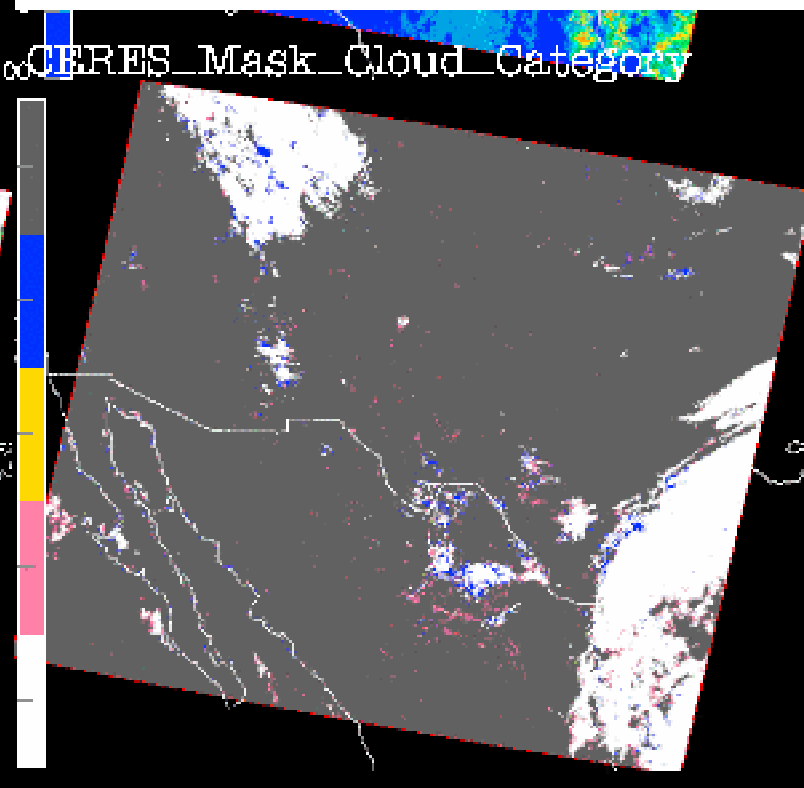
STANDARD DAYTIME MASK ALGORITHM



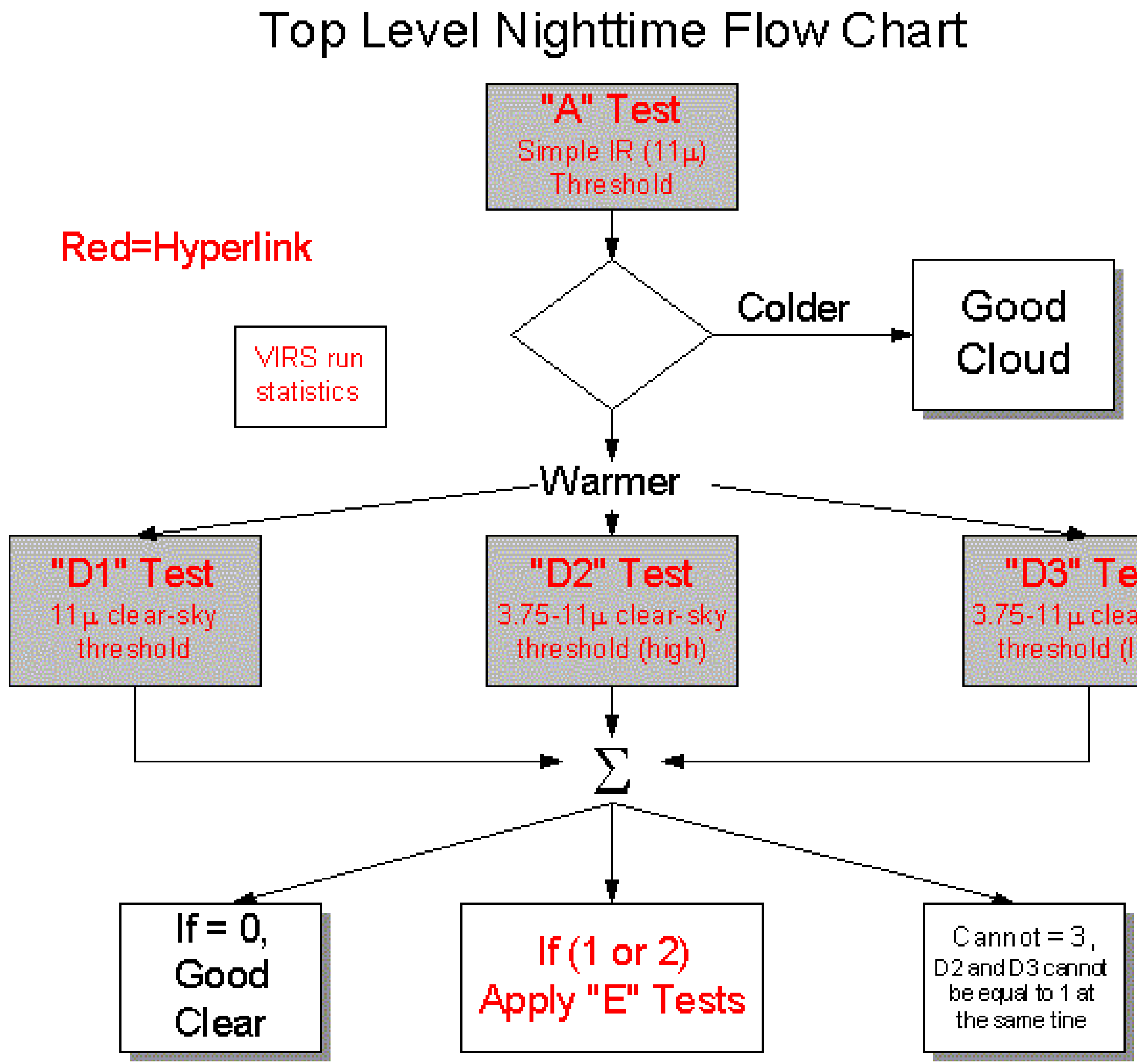


CERES CLOUD MASK 1700 UTC,12/21/00

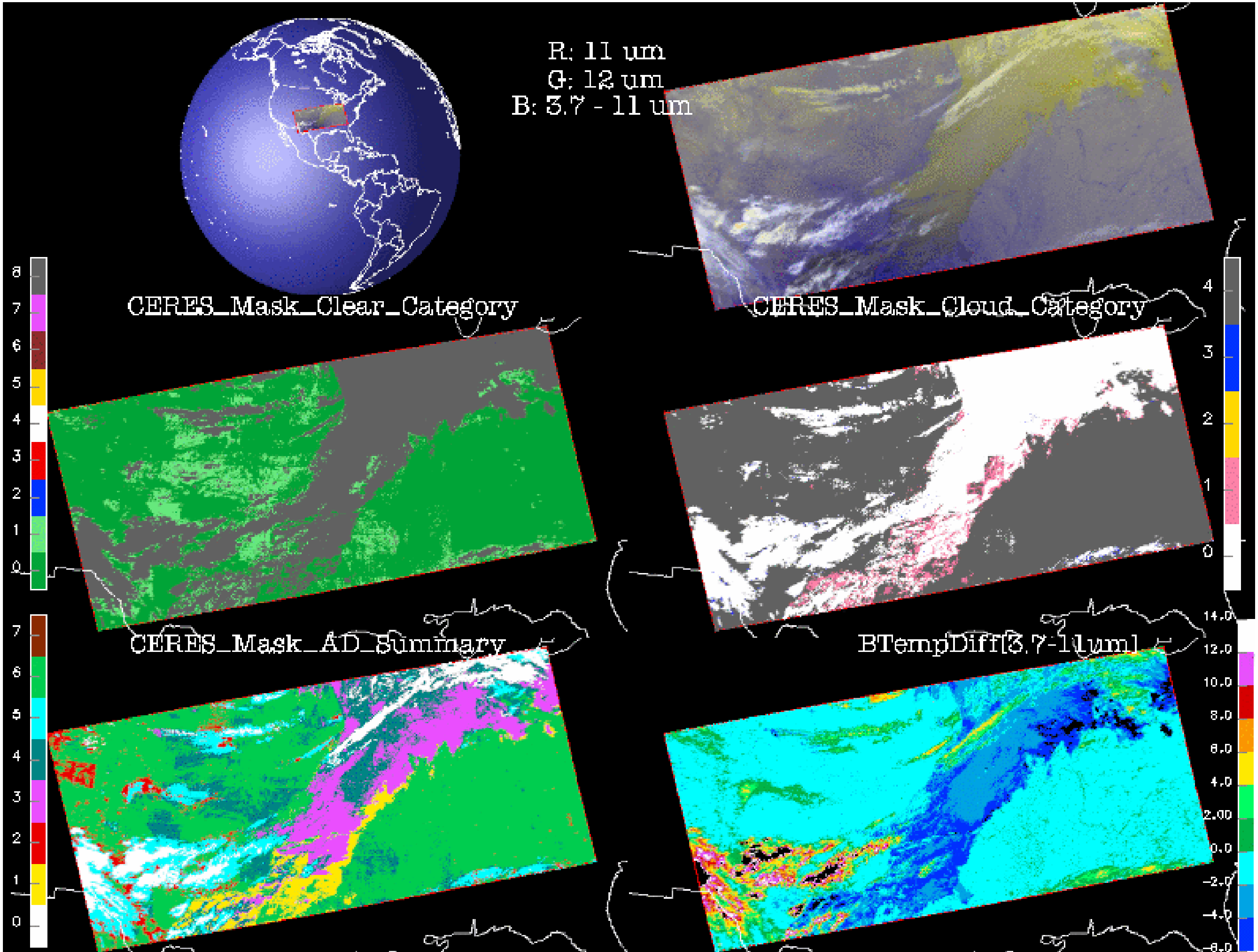




STANDARD NIGHTTIME MASK ALGORITHM



CERES CLOUD MASK & BTD(3.7 - 11) REFLECTANCE 0400 UTC,12/01/00



DAYTIME CLOUD RETRIEVALS

•VISST (Visible, infrared, solar-infrared, split-window technique)

- physically based method using 0.65, 3.7, 11, & 12 µm
- for cloudy pixels, match radiances to model values

• Yields more accurate cloud temperatures than simpler methods

- adjusts temperature (altitude) of thin clouds

• Provides basis for determining phase

- in most cases, ice & water models are distinct

Daytime Cloud Property Retrievals

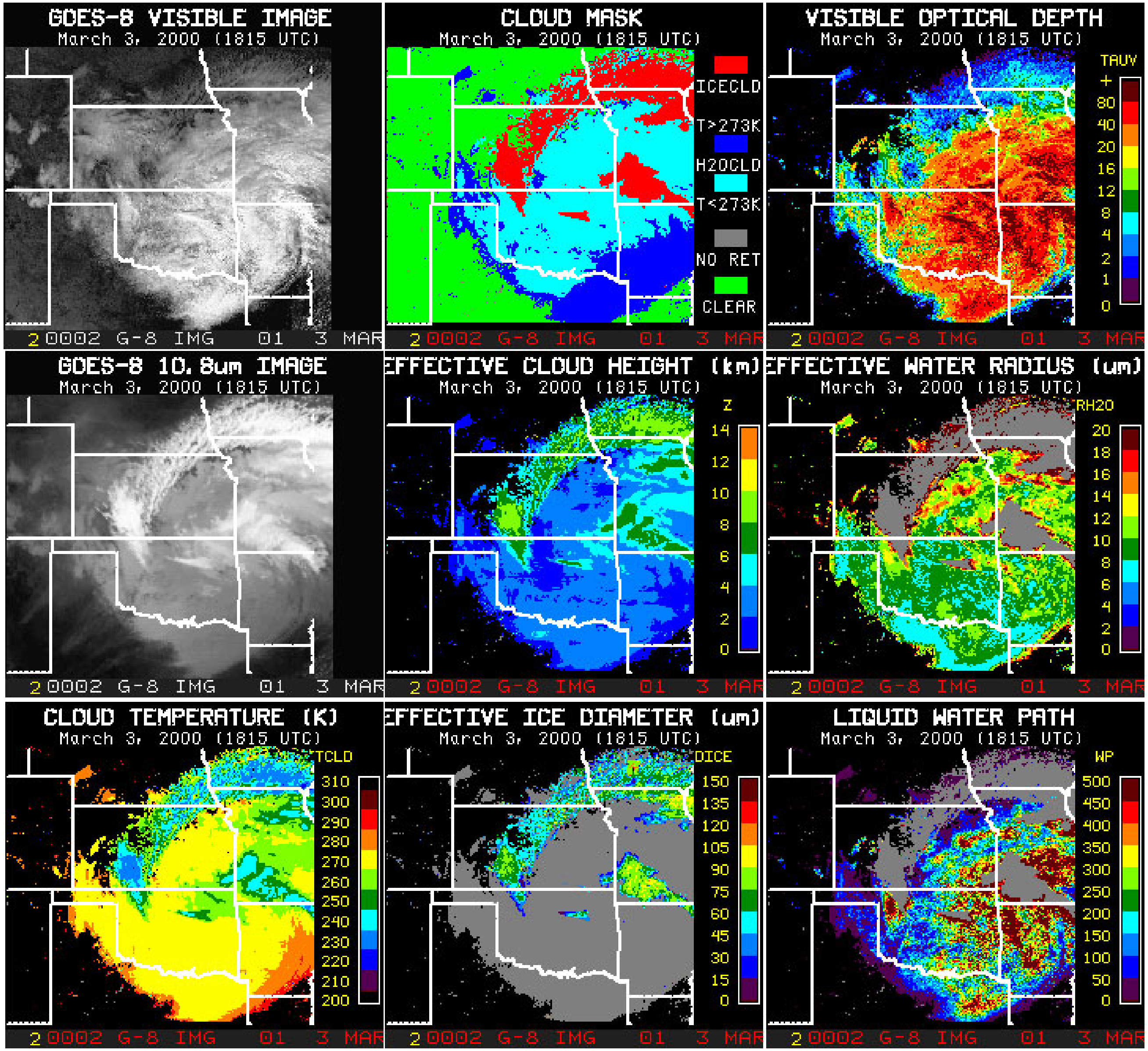
- Derive cloud properties by matching observed radiances to model calculations for water droplets ($2 < r_e < 32$ µm) and ice crystals ($6 < D_e < 135$ µm) through reflectance and emittance parameterizations
- 3.9 µm (GOES Channel 2) used for particle size retrieval
- Particle phase determined by:
  - (1) Best available model solution (2) $T_{10.8}$ - $T_{12.0}$ Difference
  - (3) Visible/IR Layer Retrieval (4) Retrieved Cloud Temperature

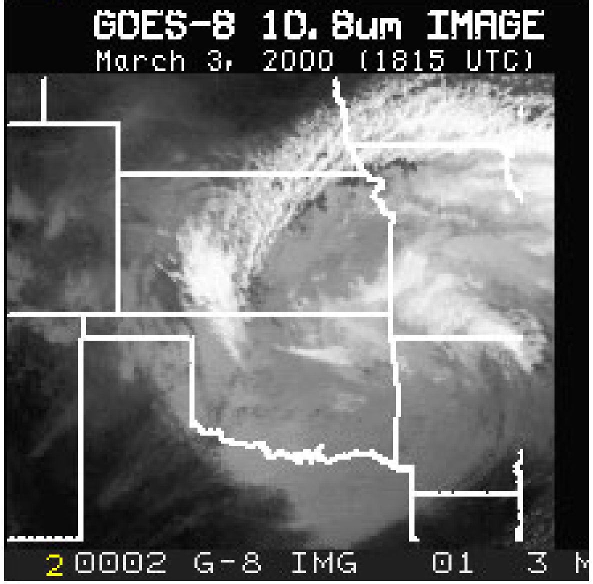
→ Cloud Tau, phase, r_e (D_e), LWP (IWP), Z_{cld} , T_{cld}

Cloud properties from GOES-8

1815 UTC

March 3, 2000

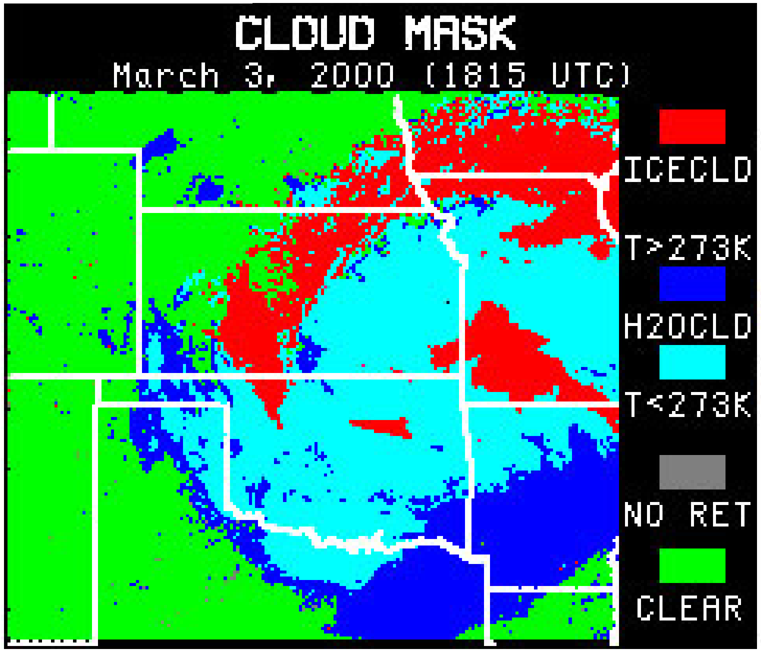


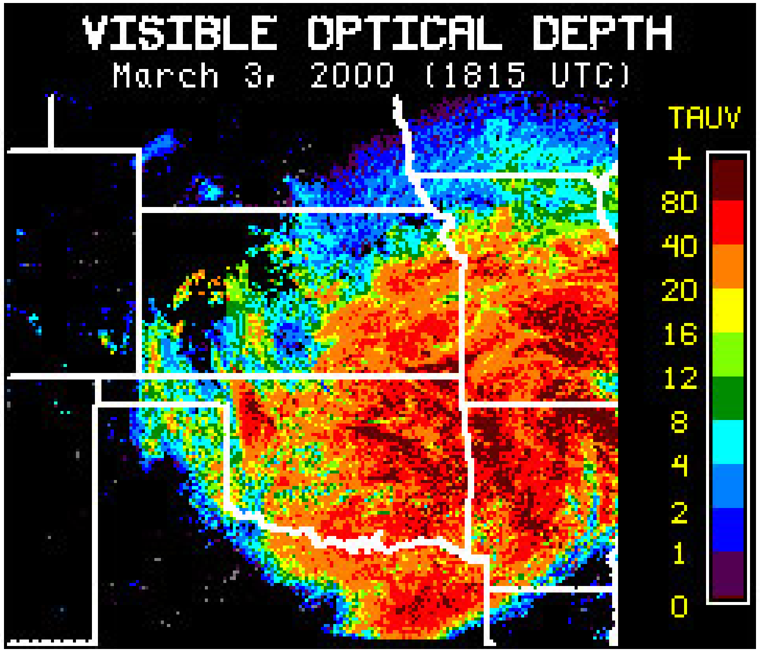


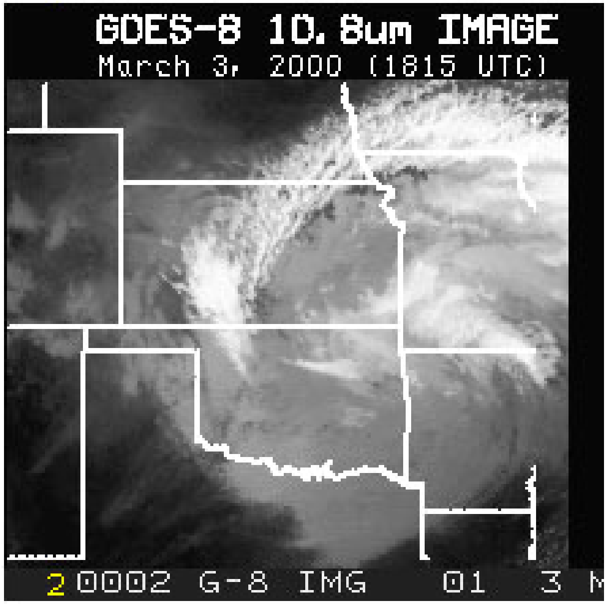
Cloud mask & optical depths from GOES-8

1815 UTC

March 3, 2000







Cloud droplet radius & LWP from GOES-8

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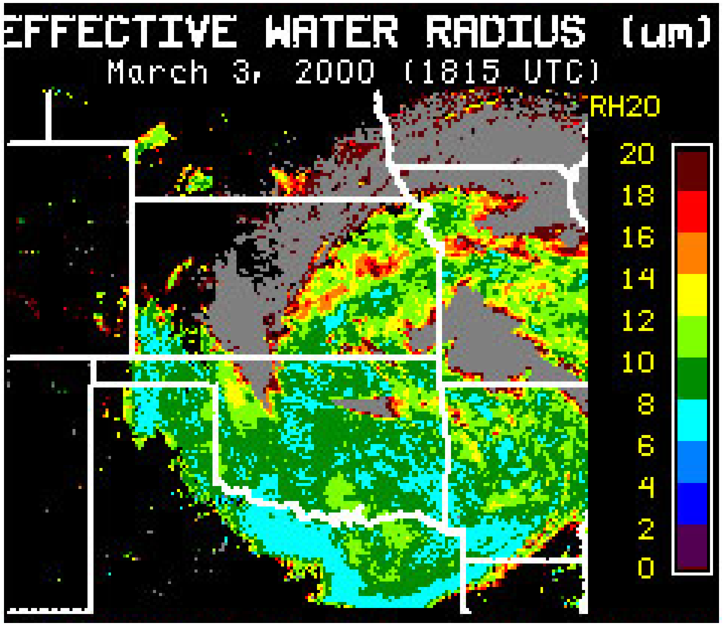
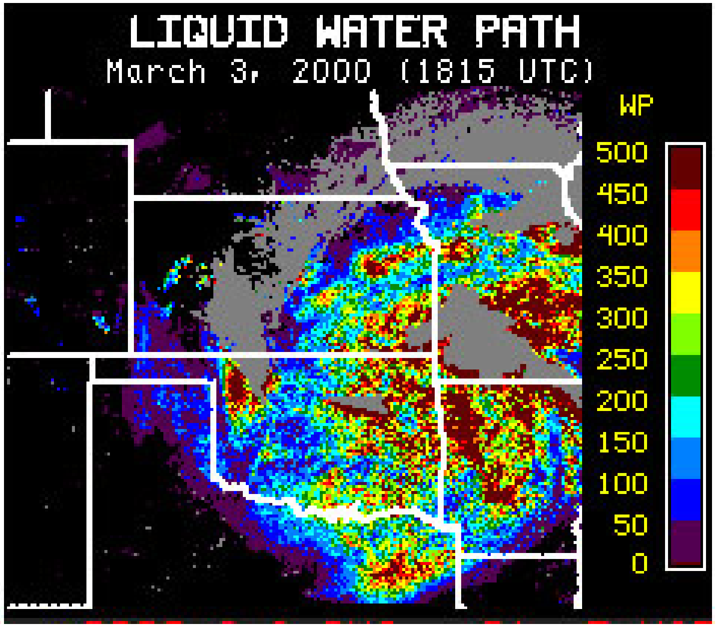
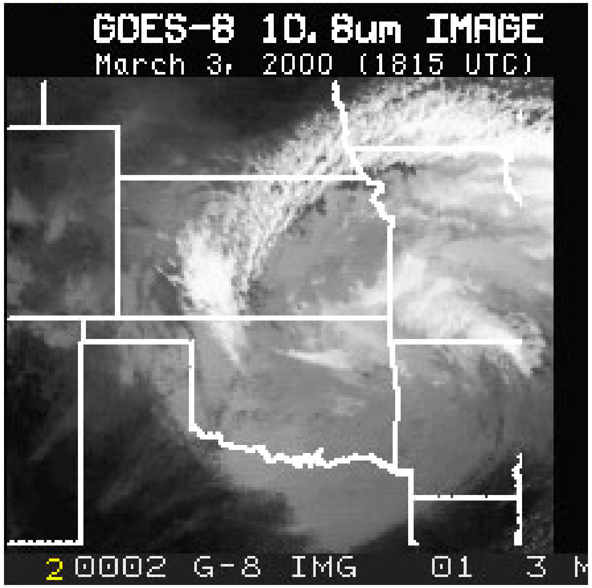
March 3, 2000



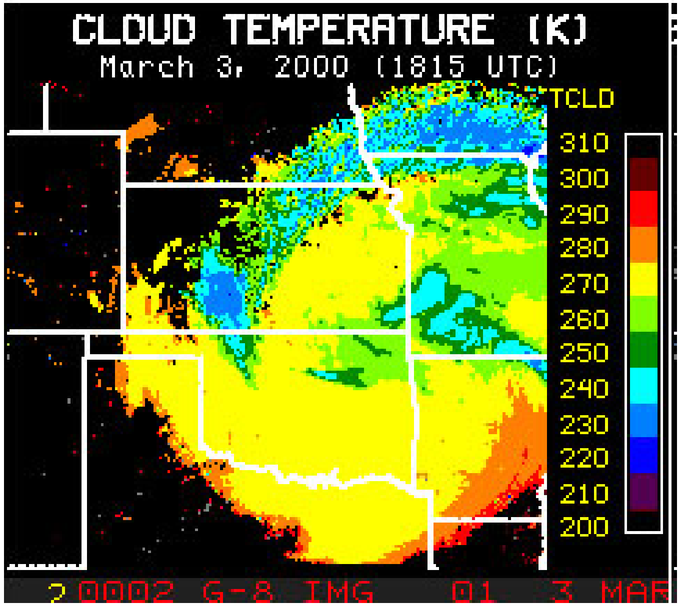


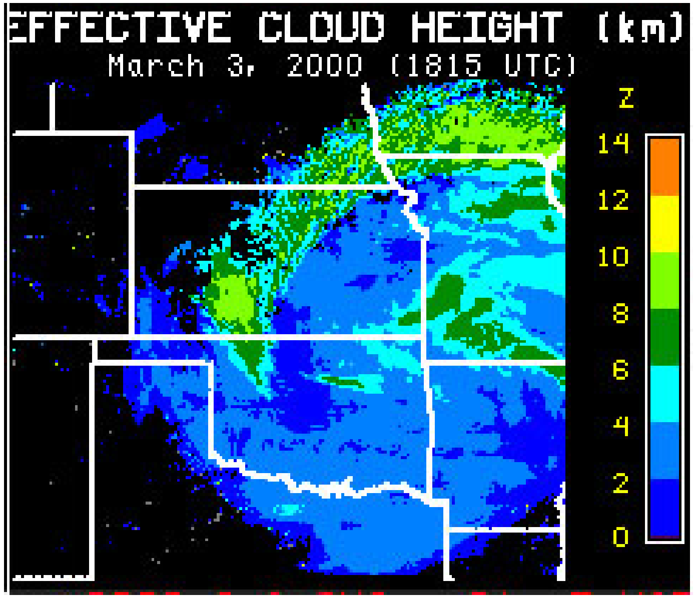


Cloud-top temperature
& height from GOES-8

1815 UTC

March 3, 2000





ARM-Sponsored Comparisons (March 2000)

Comparison of Surface, GOES and Aircraft Results (~10 hours)